Motor Coordination as Predictor of Physical Activity in Childhood

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ABSTRACT

This study considers relationships among motor coordination (MC), physical fitness (PF) and physical activity (PA) in children followed longitudinally from 6 to 10 years. It is hypothesized that MC is a significant and primary predictor of PA in children. Subjects were 142 girls and 143 boys. Height, weight and skinfolds; PA (Godin-Shephard questionnaire); MC (Körperkoordination Test für Kinder, KTK); and PF (5 fitness items) were measured. Hierarchical linear modeling with MC and PF as predictors of PA was used. The retained model indicated that PA at baseline differed significantly different between boys (48.3 MET.week^{-1}) and girls (40.0 MET.week^{-1}). The interaction of MC and one mile run/walk had a positive influence on level of PA. The general trend for a decrease in PA level across years was attenuated or amplified depending on initial level of MC. The estimated rate of decline in PA was negligible for children with higher levels of MC at 6 years, but was augmented by 2.58 and 2.47 units each year, respectively, for children with low and average levels of initial MC. In conclusion MC is an important predictor of PA in children 6-10 years of age.

Key Words

Children, longitudinal, determinants, physical fitness, movement behavior

INTRODUCTION

The benefits of regular physical activity for the health, fitness and behavior of school age children and adolescents are major topics of discussion in the context of public health (Marcus et al., 2006; Physical_Activity_Guidelines_Advisory_Committee, 2008; Strong et al., 2005). Physical activity is a complex multifactorial behavior that is influenced by a variety of biological, behavioral and environmental factors and interactions among factors. It is often assumed that enjoyable and successful participation in physical activity will promote further engagement and persistence in such activities. Indeed, participation in physical activity is associated with greater proficiency in motor skills (Butcher & Eaton, 1989; Okely et al., 2001; Wrotniak et al., 2006), while less motor proficiency is associated with lower levels of activity (Williams et al., 2008) and reduced motivation for challenging activities (Rose et al., 1998). The observations are derived from cross-sectional studies. Limited longitudinal data, on the other hand, indicate that proficiency in three basic movement skills (lateral jumping, catching a ball, one foot balance) at age 4-6 years did not predict physical activity at 12 years of age in Mexican American and American White children (McKenzie et al., 2002). The limited number of skills assessed may have influenced the results. Further study incorporating additional movement skills and other populations were recommended by the authors.

This study examines relationships among motor proficiency, physical fitness and physical activity among Portuguese children followed longitudinally from 6 to 10 years. It specifically considers the association among motor coordination (MC), performance-related physical fitness (PF) and physical activity (PA). Motor coordination and PF are evaluated as predictors of PA in a hierarchical linear model. It is hypothesized that MC is a predictor of PA in children of elementary school age.

MATERIALS AND METHODS

A longitudinal study of Azorean school children (Azore Islands, Portugal) was carried out between 2002 and 2007. Four cohorts were followed for five consecutive years. At the first evaluation children were 6, 10, 13 and 16 years of age (1st, 2nd, 3rd and 4th cohorts, respectively). Data from the first cohort who were followed from 6 to 10 years of age are the focus of this study. Body dimensions, PA and PF were evaluated annually on five occasions, while MC was evaluated over the first four years only.

Subjects. Subjects were 285 elementary school children, 142 girls and 143 boys, followed annually from 6 to10 years. The schools did not have regular physical education and sport programs. Organized physical activities were held periodically but not on a regular basis. Written informed consent was obtained from the parents of each child and the study was approved by the ethical committee of the local health authority.

Body Dimensions. Stature, body mass and the triceps and subscapular skinfolds were measured. The body mass index (BMI) and sum of skinfolds were calculated. Approximately 30% of the sample was overweight or obese, which was consistent with observations for Portuguese children of the same age, 31.5% (Padez et al., 2004).

Physical Activity. Physical activity was assessed with the Godin and Shephard questionnaire (Godin & Shephard, 1985) which was administered in an interviewer-assisted format. Children were asked to report the number of times they spent more than 15 min in activities classified as mild (3 METs), moderate (5 METs), or strenuous (9 METs) in a typical week. A total score was derived by multiplying the frequency of each category by the MET value and summing the products. Although the reported validity of this questionnaire with children is moderate, 0.32 to 0.42 (Sallis, 1993; Scerpella et al., 2002), its relative simplicity facilitated its use with children.

Motor Coordination. Motor coordination was evaluated with the Kiphard-Schilling body coordination test, Körperkoordination Test für Kinder (KTK), developed on children in Germany (Schilling, 1974). The KTK battery has four items:

[1] Balance – the child walks backward on a balance beam 3 m in length but of decreasing widths: 6 cm, 4.5 cm, 3 cm; the number of successful steps is recorded.

[2] Jumping laterally - the child makes consecutive jumps from side to side over a small beam (60 cm x 4 cm x 2 cm) as fast as possible for 15 sec. The child is instructed to keep his/her feet together; the number of correct jumps is recorded.

[3] Hopping on one leg over an obstacle – the child is instructed to hop on one foot at a time over a stack of foam squares. After a successful hop with each foot (the child clears the square without touching it and continues to hop on the same foot at least two times), the height is increased by adding a square (50 cm x 20 cm x 5 cm). The child has 3 attempts at each height and foot; the height of the final successful jump is recorded.

[4] Shifting platforms – the child begins by standing with both feet on one platform (25 cm x 25 cm x 2 cm supported on four legs 3.7 cm high) and holding a second identical platform in his/her hands; the child is instructed to place the second platform alongside the first and to step on to it; the first box is then lifted and placed alongside the second and the child steps on to it; the sequence continues for 20 s. Each successful transfer from one platform to the other is given two points (one for shifting the platform, the other for transfer the body); the number of points in 20 s is recorded. If the child falls off in the process, he/she simply gets back on to the platform and continues the test.

Although some of the items appear to measure specific components of motor performance, e.g., dynamic balance, speed and agility, balance and power, the four tests loaded on a single factor when analyzed with other items. Hence, the authors utilized the four items together as a global indicator of MC, the "motor quotient". Each performance item was scored relative to gender- and age-specific reference values for the population upon which the KTK was established (Schilling, 1974). The sum of the standardized scores for the four items provides an overall motor quotient which was used as the indicator of MC.

Physical Fitness. Physical fitness was assessed using five items (Safrit, 1995): speed - 50 yard dash, cardiorespiratory endurance - one mile walk/run, agility - 10 yard shuttle run, explosive strength - standing long jump, and static strength - handgrip dynamometry. Tests were administered at the schools in the following order with sufficient rest between items: dash, handgrip strength, shuttle run, long jump and run/walk. The same dynamometer was used throughout the study and was regularly calibrated.

Quality Control. All measurements and tests were taken during a two month period in September and October of each year, thus reducing potential seasonal variation. Reliability of measurements and tests was estimated with intraclass correlations. Estimated reliability was high for height and weight, 0.98 and 0.99, respectively; moderately high to high for fitness items, 0.72 to 0.99, and for motor coordination test items, 0.75 to 0.91; and moderately high for estimated level of physical activity, 0.75.

Statistical analysis. Motor coordination and PF were evaluated as predictors of physical activity in a hierarchical linear model. Since repeated measures were nested within subjects, the longitudinal data set was treated as hierarchical. Consequently, there were predictors for subjects (level 2) and for the trajectories of each subject (level 1). In order to include initial MC scores as a second level predictor in the analysis, children were divided into tertiles as: low, middle and high. This allows the analysis of changes in PA by level of MC (low, middle and high) at baseline (6 years).

After testing all variables for normality, two-level hierarchical linear models were tested, with PA as the dependent variable (Table 1). The first two models evaluate the conditions for using hierarchical linear techniques to model changes in PA over time. The autoregressive structure of the covariance matrix was tested in model 3. MC and PF variables and their interactions were tested as predictors of PA in the other models. Both level 1 and level 2 predictors were retained in the models only if they had a significant effect. Maximum likelihood estimation was used with the HML5 statistical software (Raudenbush et al., 2001). A robust standard errors estimation analysis was used to control for the non-normality of some variables. The decision about the model retained was based on parsimony, using the Akaike Information Criterion (AIC) (Hox, 2002).

Table 1 about here

RESULTS

Descriptive statistics for the BMI, skinfolds, MC, PF items and PA at each observation are summarized in Table 2. Boys have, on average, consistently higher levels of MC and PA, and better performances on the fitness items at each observation compared to girls. The BMI is similar between boys and girls, but girls have, on average, thicker skinfolds at each observation.

Table 2 about here

Both boys and girls exhibit, on average, an overall decrease in PA with age, especially across the first three observations. Based on age independent quotients, levels of MC are similar across the four annual assessments in boys, while levels of MC in girls tend to increase slightly from observations one through three and then decline. The BMI, skinfolds and individual fitness items increase, on average, across observations in boys and girls.

Nine consecutive hierarchical models were tested (Table 1) to ascertain the prediction of PA. Results for the first two models evaluate the conditions for using the hierarchical linear technique to model changes in PA over time. The intraclass correlation coefficient is 0.15 for the intercept-only model (model 1), indicating that 15% of the variance in PA is due to differences among subjects; in contrast, 85% of the variance is due to intra-individual changes in PA across time. Results for model 2 indicate a unique rate of change in PA relative to baseline for each subject. Moreover, the rates can be modeled in the hierarchical linear framework.

Model 3 shows no significant effect of the autoregressive structure of the covariance matrix; consequently, this structure is not included in the models tested subsequently. Gender significantly differentiates individual results in model 4; PA of boys is higher than girls. Of the eight variables tested (MC, one mile run/walk, BMI, sum of skinfolds, 50 yards dash, 10 yards shuttle-run, standing long jump, handgrip dynamometry) as predictors of PA in model 5, only MC and the one mile run/walk are significant. The results of model 6 show an interaction between MC and the one mile run/walk. When initial levels of MC are included in model 7 as dummy variables representing the low and middle tertiles of initial MC (ILMC1, ILMC2)], both are significant predictors of PA indicating that children of with different levels of MC differ significantly in level of PA. Children within the highest MC level had a higher level of PA. The time effect is included in the random part of model 8; the results indicate that each child has his/her own trajectory of change.

Subsequent testing resulted in the final model summarized in Table 3. Boys and girls differ significantly in mean level of PA at baseline (boys 48.3 $MET.week^{-1}$; girls 40.0 $MET.week^{-1}$). The interaction between MC and the one mile run/walk has a positive influence on level of PA (for each unit change in the product of MC and the inverse of one mile run/walk PA changes by 17.96 units). There is a general decrease of PA over time, but this tendency is attenuated or augmented depending on the initial level of MC of individual children (Figure 1). On average, the decrease in PA is 2.58 and 2.47 units per year for children classified in the low and middle tertiles of initial MC and remains stable for children on the high tertile of initial MC.

Table 3 about here

Figure 1 about here

DISCUSSION

Results of the present study indicate that MC as measured by the four items of Kephard-Schilling (KTK) test is a significant predictor of PA in children 6-10 years of age. Moreover, initial level of MC is associated with subsequent changes in level of PA during childhood. Children with high levels of MC at six years of age show negligible changes in levels of PA over the next three years compared to children with low and middle levels of MC. The gradients shown in Figure 1 suggest that children with low initial levels of MC decline the most in PA over the age interval considered, followed by those with mid-level initial MC. On the other hand, children with high initial levels of MC show stable levels of PA over time that are higher than children with lower initial levels of MC.

The final hierarchical linear model supports the hypothesis that MC is an important predictor of PA during childhood. Gender and one component of PF, the one mile run/walk, are also significant predictors. The one mile run/walk positively and significantly interacts with MC. Nevertheless, the strong effect of initial level of MC implies that children classified in the high tertile of MC at 6 years of age tend to maintain PA levels over time, while peers in the low and middle tertiles of MC at 6 years tend to show a decline in PA across time. This conclusion is especially relevant since children in the three MC groups at baseline do not significantly differ in level of PA at baseline (data not shown). It appears that the influence of MC on level of PA is amplified over time. It is possible that limited motor competence may lead to unpleasant experiences in movement activities whereas better motor competence is associated with more favorable experiences which encourage involvement in PA. Of interest, the BMI, skinfolds and the remaining four performance-related PF items (speed, agility, explosive power, static strength) were not significant predictors of change in PA in this longitudinal sample of Azorean children. The observations suggest that at these young ages, body size, subcutaneous fatness and performance-related PF are not primary factors related to PA as assessed in this study. The interaction between MC and the one mile run/walk implies that both MC and aerobic capacity have a combined positive effect on the individual PA. Relatively few studies have considered the relationship between MC and PA, and they are either cross-sectional or short term (Butcher & Eaton, 1989; Okely, Booth, 2001; Wrotniak, Epstein, 2006). Conclusions of these studies highlight the association between MC and PA, but statements of causality are not warranted. Studies of correlates of PA in children ordinarily do not include measures of MC. In a mixed-ethnic sample of 4th and

5th grade children (circa 9-10 years), only a small percentage of the variance in PA over a 20-month interval was explained by MC, 12% in boys and 6% in girls. Significant predictors were psychological and parent-related variables in both sexes and an interaction between activity preference and skinfold thickness in girls (Sallis et al., 1999). In a cross-sectional survey of American White and Black youth (mean age of 11.4±0.6 years), psychological and environmental variables in hierarchical linear regression analyses explained a low percentage of variance in moderate and vigorous PA, 1% to 13% in boys and 1% to 8% in girls (Trost et al., 1999).

Consistent with the literature (Lopes et al., 2007; Reilly et al., 2004; Sarkin et al., 1997; Trost et al., 2002), results of the present study showed that boys have higher levels of PA than girls and that level of PA tends to decline with age in both genders across childhood. However, the present study also showed a significant role for proficiency in movement skill or MC as an important predictor of change in PA over an interval of three years in childhood. Motor proficiency is also a determinant of actual or perceived physical competence in children which are in turn predictors of PA in youth (Ferguson et al., 1989; Southall et al., 2004; Ulrich, 1987).

Initial observations in the present study were made at 6 years of age. The results have potential implications for preschool experiences as an influence on the MC of children. Information on the pre-school experiences of the sample is not available. Associations between proficiency in basic movement skills and habitual PA have been reported as relatively weak in children 4.2±0.5 years of age (Fisher et al., 2005). On the other hand, PA (Reilly et al., 2006) and specific motor skill instructional (Goodway & Branta, 2003) interventions are associated with improvements in basic motor skills in preschool children. In the context of observations in the present study, the preceding would seem to suggest that improving the motor proficiency of preschool children has the potential to influence PA beyond the preschool years.

Play is an accepted medium for learning and physical activity among preschool children (Bjorklund & Brown, 1998; Pelligrini et al., 1998). Although time in free play does not receive much attention in the context of the development of motor proficiency, it is reasonable to assume that play provides an opportunity for trying and developing movement skills in different contexts. Of relevance to both play and physical activity in preschool children, time in play has declined by an estimated 509 minutes per week while time in day care and school has increased by 405 minutes per week between 1981 and 1997 among American children 3-5 years of age (Sturm, 2005). Children tend to be physically active during play and it is possible that those who are more proficient in MC may be more likely to engage and persist in challenging physically active tasks. If this is so, investing in the improvement of motor proficiency in young children has potentially relevant policy implications related to PA and health.

Although the present study has major merit in being longitudinal, it is limited because a more direct measure of PA was not used. Nevertheless, the questionnaire that was used has reasonable validity and reliability (Sallis, 1993; Scerpella, Tuladhar, 2002). Another limitation is the lack of specific information on the preschool backgrounds of the subjects which may have conditioned their status at elementary school age. Nevertheless, data from the longitudinal study of Azorean children suggest that MC is an important determinant of PA in childhood.

Perspectives

Determinants or correlates of PA in young children are apparently many, but interest in the role of motor proficiency as a predictor of PA is relatively recent. Most studies to date are cross-sectional which limits the observed associations between PA and motor proficiency. The longitudinal design of the present study provides a degree of causality for the relationship between motor proficiency and PA. MC is an important predictor of PA during childhood. From the public heath perspective, improving the motor proficiency of young children has potentially relevant policy implications relating to PA per se and to the benefits of PA for health.

Growth, motor development and physical fitness are in part influenced by genotype, of course interacting with the environments in which children are reared. How an individual responds to environmental conditions, for example, systematic physical activity or instruction is also influenced in part by genotype (Bouchard et al., 1997; Malina et al., 2004). The processes of biological growth and maturation and of behavioral development are dynamic and of course unique to individuals. Observations from this longitudinal study highlight the potential importance of motor coordination as a factor influencing level of physical activity during childhood. The observations also have implications for children with low levels of motor coordination. Systematic instruction by specialists and perhaps trained parents and adequate time for practice are significant factors that contribute to improvements in movement proficiency in young children (Malina, 2008).

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Table 1 - Summary of models tested

Step	Model
1	Intercept only model: to test the amount of variance between subjects.
2	Unconditional linear growth model: to estimate the “moments” of the trajectories, i.e., the mean intercept, the mean slope and the variance around the baseline mean value.
3	Autoregressive model: to test if previous level of physical activity is a predictor of the subsequent level.
4	Inclusion of sex as a level 2 predictor: to test for significant differences between boys and girls.
5	Inclusion of motor coordination, physical fitness and body dimensions as level 1 predictors: to test if these variables are significant predictors of physical activity.
6	Inclusion of a variable representing the interaction between MC and one mile run/walk (product of MC with inverted values of one mile run/walk).
7	Inclusion of two dummy variables representing initial levels of motor coordination [tertile 1 of initial level of MC (ILMC1) and tertile 2 of initial level of MC (ILMC2)] as a level 2 predictor: to test whether children for each of the 3 initial levels of motor coordination (low, middle and high level) have significant different levels of PA.
8	Inclusion of the random effect of time to test whether there are inter-individual differences between subjects in changes in motor coordination over time.
9	Inclusion of the cross level interaction between time effect and ILMC1 and ILMC2: to test if there are significant differences between subjects in intra-individual change according to initial level of motor coordination.

Table 2 - Means and standard deviations for characteristics of the 142 girls and 143 boys at each observation.

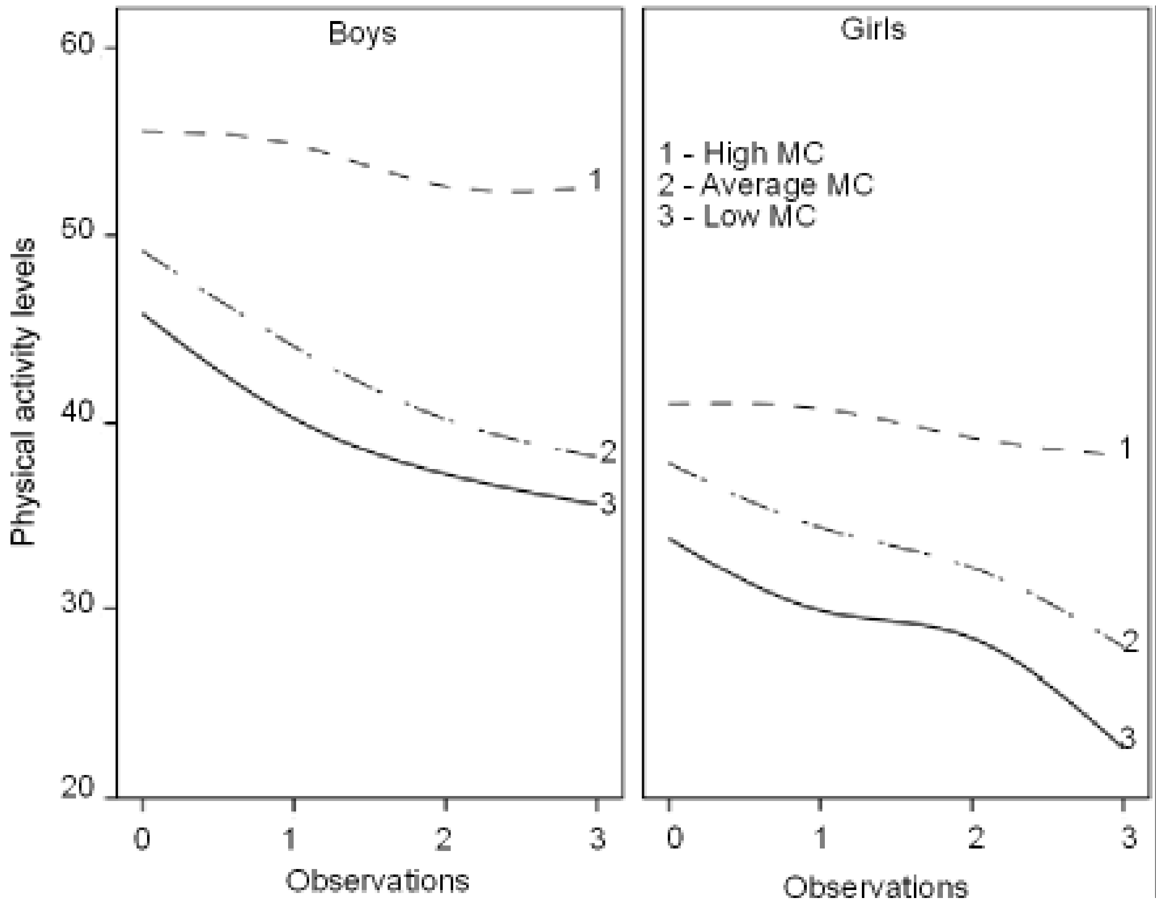
Observations	0 – baseline (6 years of age)		1 (7 years of age)		2 (8 years of age		3 (0 years of age)		4 (10 years of age)	
	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
MC (points)	70.3(12.6)	82.1(12.2)	75.0(13.4)	82.2(14.1)	77.7(14.4)	80.6(14.5)	71.3(16.8)	79.8(17.1)	--	--
PA (Met(s)·week^{-1})	41.4(32.0)	51.5(31.1)	36.0(22.2)	44.2(25.1)	26.0(21.4)	36.4(22.7)	33.4(20.1)	48.3(23.8)	26.3(16.7)	41.7(20.2)
Height (cm)	117.5(5.4)	119.0(5.1)	122.5(5.8)	123.9(5.6)	128.1(6.2)	129.6(5.9)	133.2(6.5)	134.8(6.4)	139.4(7.2)	139.8(6.6)
Weight (kg)	23.9(4.6)	24.6(5.1)	26.1(5.6)	26.8(6.1)	29.6(6.5)	30.3(7.6)	33.4(7.8)	34.4(9.0)	37.3(9.0)	37.7(9.8)
BMI (kg·m^{-2})	17.2(2.4)	17.3(2.5)	17.3(2.7)	17.3(2.8)	17.9(2.9)	17.9(3.2)	18.6(3.3)	18.7(3.6)	19.1(3.5)	19.1(3.7)
Sum of skinfolds (mm)	19.3(8.3)	16.0(8.6)	20.4(9.6)	16.4(8.1)	22.8(9.8)	18.5(10.3)	24.8(11.4)	20.7(11.6)	26.6(11.4)	22.5(12.1)
50 yd run (sec)	12.6(1.5)	11.8(1.5)	11.8(1.2)	11.1(1.2)	11.0(1.2)	10.3(1.1)	10.5(1.0)	9.8(1.0)	9.9(1.1)	9.3(0.9)
Handgrip (kg)	8.1(1.8)	9.8(2.1)	10.1(2.2)	11.9(2.6)	11.5(2.6)	13.6(3.0)	13.4(3.0)	15.7(3.2)	15.0(3.4)	17.3(3.4)
Standing long jump (m)	0.9(0.2)	1.0(0.2)	1.0(0.2)	1.1(0.2)	1.1(0.2)	1.1(0.2)	1.1(0.3)	1.2(0.2)	1.2(0.2)	1.3(0.2)
Shuttle run (sec)	15.1(1.6)	14.4(1.3)	14.6(1.6)	14.1(1.6)	13.8(1.3)	13.4(1.4)	13.5(1.7)	12.8(1.5)	12.4(1.0)	12.0(1.5)
One mile run/walk (min)	14.1(2.6)	13.0(2.7)	14.6(3.4)	13.8(4.0)	14.2(3.0)	13.4(3.7)	13.8(2.4)	12.4(2.9)	13.2(2.6)	11.4(3.0)

Table 3 - Specification of parameters in the final model with standard errors (SE) and confidence intervals.

Parameter	Estimate(SE)	95% Confidence Interval
Fixed effect		
Intercept	39.67 (1.83)	36.54 — 43.72
Time	-1.25 (0.98)	-3.28 — 0.56
Gender	8.09 (1.76)	4.64 — 11.54
Time * ILMC1	-2.44 (1.08)	-4.55 — -0.32
Time * ILMC2	-2.34 (0.98)	-4.26 — -0.41
MC * One mile run/walk	18.55 (2.64)	13.37 — 23.72

Figure legends

Figure 1 – Predicted values for change in physical activity levels in children classified by initial levels of motor coordination.


Boys
Girls
Physical activity levels
60
50
40
30
20
0
1
2
3
Observations
1 - High MC
2 - Average MC
3 - Low MC
1
2
3